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CHEMISTRY
HIGHER LEVEL
PAPER 2

Candidate session number

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Monday 9 May 2011 (afternoon)

2 hours 15 minutes

Examination code

2	2	1	1	–	6	1	0	8

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer two questions.
- Write your answers in the boxes provided.

31 pages

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Answers written on this page will not be marked.

SECTION A

*Answer **all** questions. Write your answers in the boxes provided.*

1. Methanol is made in large quantities as it is used in the production of polymers and in fuels. The enthalpy of combustion of methanol can be determined theoretically or experimentally.

$$CH_3OH(l) + 1\tfrac{1}{2}O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

	$CH_3OH(l)$	$O_2(g)$	$CO_2(g)$	$H_2O(g)$
Standard enthalpy of formation, $\Delta H_f^{\ominus}$ / kJ mol^{-1}	–239	0	–394	–242
Entropy, $S^{\ominus}$ /J K^{-1} mol^{-1}	240	205	214	189

(a) Using the information from the table above, determine the theoretical enthalpy of combustion of methanol. *[2]*

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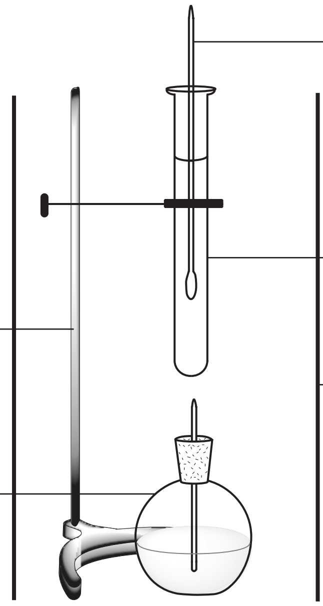
(Question 1 continued)

(b) The enthalpy of combustion of methanol can also be determined experimentally in a school laboratory. A burner containing methanol was weighed and used to heat water in a test tube as illustrated below.



The following data were collected.

Initial mass of burner and methanol / g	80.557
Final mass of burner and methanol / g	80.034
Mass of water in test tube / g	20.000
Initial temperature of water / °C	21.5
Final temperature of water / °C	26.4

(i) Calculate the amount, in mol, of methanol burned. *[2]*

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(This question continues on the following page)

(Question 1 continued)

(ii) Calculate the heat absorbed, in kJ, by the water. *[3]*

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(iii) Determine the enthalpy change, in kJ mol^{-1}, for the combustion of methanol. *[2]*

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(Question 1 continued)

(c) The Data Booklet value for the enthalpy of combustion of methanol is -726 kJ mol^{-1}. Suggest why this value differs from the values calculated in parts (a) and (b).

(i) Part (a) *[1]*

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(ii) Part (b) *[1]*

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(d) Determine the $\Delta S^{\ominus}$ for the combustion of methanol. *[2]*

$$CH_3OH\,(l) + 1\tfrac{1}{2}O_2\,(g) \rightarrow CO_2\,(g) + 2H_2O\,(g)$$

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(Question 1 continued)

(e) Using the enthalpy of combustion for methanol from Table 12 of the Data Booklet and the $\Delta S^{\ominus}$ determined in part (d), calculate the standard free energy change for the combustion of methanol. *[3]*

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(f) Explain whether changing the temperature will alter the spontaneity of the reaction. *[1]*

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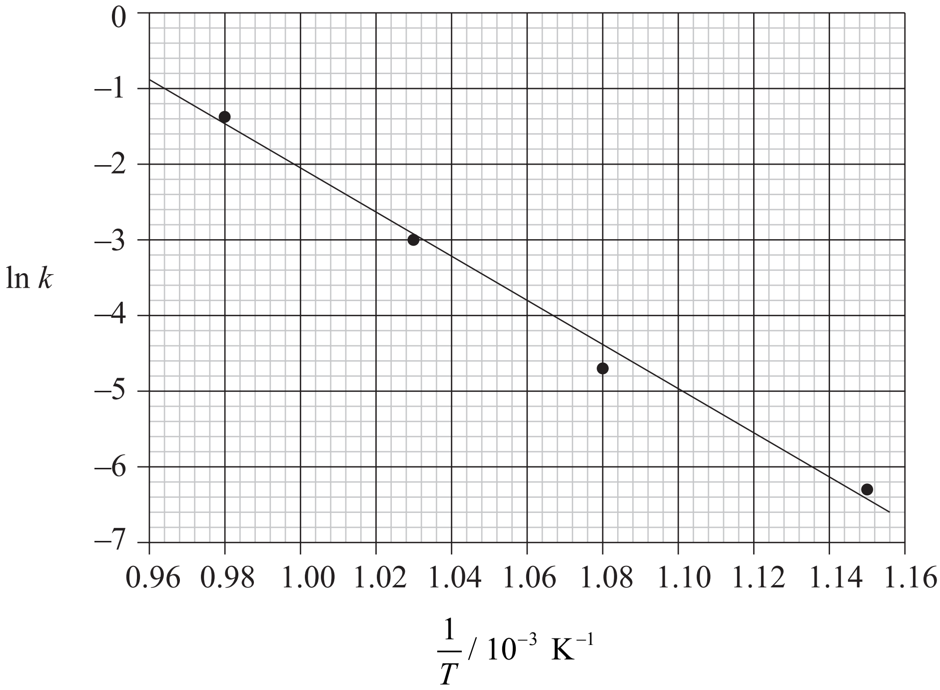
2. Consider the following graph of ln k against $\frac{1}{T}$ (temperature in Kelvin) for the second order decomposition of N_2O into N_2 and O.

$$N_2O \rightarrow N_2 + O$$



(a) State how the rate constant, k varies with temperature, T. *[1]*

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(b) Determine the activation energy, E_a, for this reaction. *[3]*

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(Question 2 continued)

(c) The rate expression for this reaction is rate = $k\,[N_2O]^2$ and the rate constant is $0.244\ dm^3\ mol^{-1}\ s^{-1}$ at 750 °C.

A sample of N_2O of concentration $0.200\ mol\ dm^{-3}$ is allowed to decompose. Calculate the rate when 10 % of the N_2O has reacted. *[2]*

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3. (a) Explain why the relative atomic mass of cobalt is greater than the relative atomic mass of nickel, even though the atomic number of nickel is greater than the atomic number of cobalt. *[1]*

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(b) Deduce the numbers of protons and electrons in the ion Co^{2+}. *[1]*

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(c) Deduce the electron configuration for the ion Co^{2+}. *[1]*

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(d) Identify a radioactive isotope of cobalt **and** state **one** of its uses. *[1]*

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4. Methanol may be produced by the exothermic reaction of carbon monoxide gas and hydrogen gas.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H^{\ominus} = -103 \text{ kJ}$$

(a) State the equilibrium constant expression, K_c, for the production of methanol. *[1]*

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(b) State and explain the effect of changing the following conditions on the amount of methanol present at equilibrium:

(i) increasing the temperature of the reaction at constant pressure. *[2]*

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(ii) increasing the pressure of the reaction at constant temperature. *[2]*

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(This question continues on the following page)

(Question 4 continued)

(c) The conditions used in industry during the production of methanol are a temperature of 450 °C and pressure of up to 220 atm. Explain why these conditions are used rather than those that could give an even greater amount of methanol. *[2]*

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(d) A catalyst of copper mixed with zinc oxide and alumina is used in industry for this production of methanol. Explain the function of the catalyst. *[1]*

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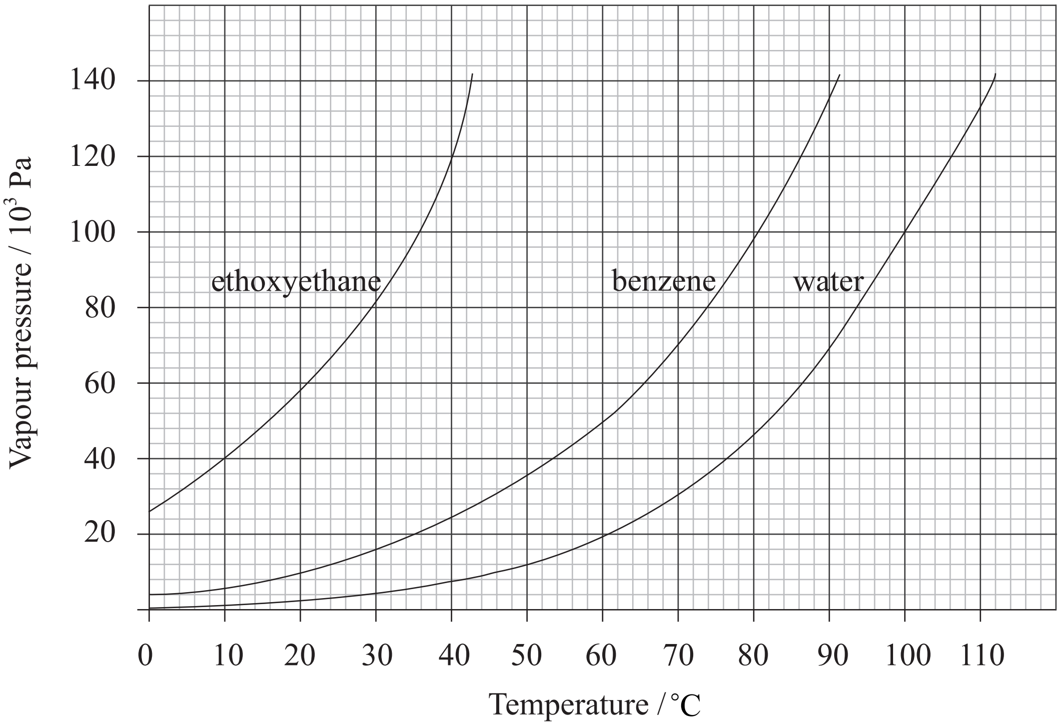
5. The graph below illustrates how the vapour pressures of ethoxyethane, $CH_3CH_2OCH_2CH_3$, benzene, C_6H_6, and water, H_2O, change with temperature.



(a) Using data from the graph, explain the difference in vapour pressure of ethoxyethane, benzene and water at 30 °C. *[4]*

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(b) Use the graph to determine the boiling point of benzene at standard pressure. *[1]*

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SECTION B

*Answer **two** questions. Write your answers in the boxes provided.*

6. Carbon and silicon belong to the same group of the periodic table.

(a) Describe and compare **three** features of the structure and bonding in the three allotropes of carbon: diamond, graphite and C_{60} fullerene. *[6]*

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(b) Both silicon and carbon form oxides.

(i) Describe the structure and bonding in SiO_2. *[2]*

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(Question 6 continued)

(ii) Explain why silicon dioxide is a solid and carbon dioxide is a gas at room temperature. *[2]*

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(c) Describe the bonding within the carbon monoxide molecule. *[2]*

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(d) Describe the delocalization of pi (π) electrons and explain how this can account for the structure and stability of the carbonate ion, CO_3^{2-}. *[3]*

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(Question 6 continued)

(e) Explain the meaning of the term *hybridization*. State the type of hybridization shown by the carbon atoms in carbon dioxide, diamond, graphite and the carbonate ion. *[5]*

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(f) (i) Explain the electrical conductivity of molten sodium oxide and liquid sulfur trioxide. *[2]*

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(Question 6 continued)

(ii) Samples of sodium oxide and solid sulfur trioxide are added to separate beakers of water. Deduce the equation for each reaction and predict the electrical conductivity of each of the solutions formed. *[3]*

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7. (a) Two compounds, **A** and **D**, each have the formula C_4H_9Cl.

Compound **A** is reacted with dilute aqueous sodium hydroxide to produce compound **B** with a formula of $C_4H_{10}O$. Compound **B** is then oxidized with acidified potassium manganate(VII) to produce compound **C** with a formula of C_4H_8O. Compound **C** resists further oxidation by acidified potassium manganate(VII).

Compound **D** is reacted with dilute aqueous sodium hydroxide to produce compound **E** with a formula of $C_4H_{10}O$. Compound **E** does not react with acidified potassium manganate(VII).

Deduce the structural formulas for compounds **A**, **B**, **C**, **D** and **E**. *[5]*

A:

B:

C:

D:

E:

(This question continues on the following page)

(Question 7 continued)

(b) Deduce an equation for the reaction between propanoic acid and methanol. Identify the catalyst and state the name of the organic compound, **X**, formed. *[4]*

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(c) In an experiment conducted at 25.0 °C, the initial concentration of propanoic acid and methanol were 1.6 mol dm^{-3} and 2.0 mol dm^{-3} respectively. Once equilibrium was established, a sample of the mixture was removed and analysed. It was found to contain 0.80 mol dm^{-3} of compound **X**.

(i) Calculate the concentrations of the other three species present at equilibrium. *[3]*

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(Question 7 continued)

(ii) State the equilibrium constant expression, K_c, and calculate the equilibrium constant for this reaction at $25.0\,^{\circ}\mathrm{C}$. *[2]*

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(d) (i) 2-chloro-3-methylbutane reacts with sodium hydroxide via an S_N2 mechanism. Explain the mechanism by using curly arrows to represent the movement of electron pairs. *[4]*

(ii) Explain why the hydroxide ion is a better nucleophile than water. *[2]*

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(Question 7 continued)

(iii) 1-chlorobutane can be converted to a pentylamine via a two stage process. Deduce equations for each step of this conversion including any catalyst required **and** name the organic product produced at **each** stage. *[5]*

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8. (a) (i) Define the terms *acid* and *base* according to the Brønsted-Lowry theory. Distinguish between a weak base and a strong base. State **one** example of a weak base. *[3]*

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(ii) Weak acids in the environment may cause damage. Identify a weak acid in the environment **and** outline **one** of its effects. *[2]*

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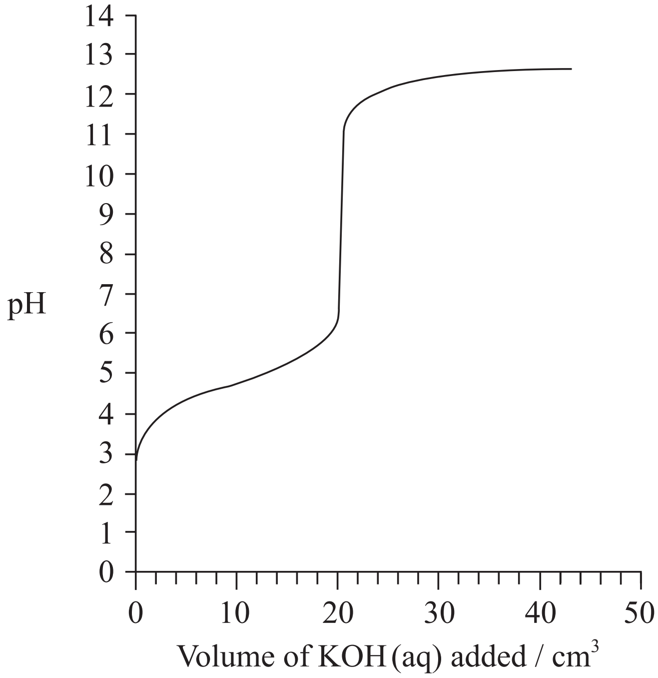
(Question 8 continued)

(iii) The graph below indicates the pH change during the titration of 20.0 cm^3 of 0.100 mol dm^{-3} of CH_3COOH(aq) with 0.100 mol dm^{-3} KOH(aq). From the graph, identify the volume of KOH(aq) and the pH at the equivalence point. *[2]*



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(iv) Explain how the graph could be used to determine the pK_a of ethanoic acid **and** determine the pK_a value for these data. *[2]*

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(Question 8 continued)

(v) Sketch a graph, similar to the graph on the previous page, to indicate the change in pH during a titration of 25.0 cm^3 of 0.100 mol dm^{-3} $HNO_3(aq)$ with 0.100 mol dm^{-3} KOH (aq). On your graph, clearly indicate the starting pH value, the equivalence point, the pH at the equivalence point and the final pH reached. *[4]*

(b) (i) Describe how an indicator works. *[3]*

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(Question 8 continued)

(ii) Using Table 16 of the Data Booklet, identify the most appropriate indicator for the titration of ethanoic acid with potassium hydroxide. Explain your choice. *[2]*

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(c) Explain, using an equation, whether a solution of 0.10 mol dm^{-3} $FeCl_3(aq)$ would be acidic, alkaline or neutral. *[2]*

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(d) Determine the pH of the solution resulting when 100 cm^3 of 0.50 mol dm^{-3} $HCl(aq)$ is mixed with 200 cm^3 of 0.10 mol dm^{-3} $NaOH(aq)$. *[5]*

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9. (a) The conditions used in an electrolytic cell can determine the products formed.

(i) Draw an electrolytic cell illustrating the electrolysis of molten nickel(II) bromide, $NiBr_2$. Include in the diagram the direction of the electron flow, the polarity of electrodes and state the half-equations for the product formed at each electrode. *[5]*

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(ii) Deduce the equations for the formation of the major product at the positive electrode (anode) when the following aqueous solutions are electrolysed.

- dilute sodium chloride
- concentrated sodium chloride *[2]*

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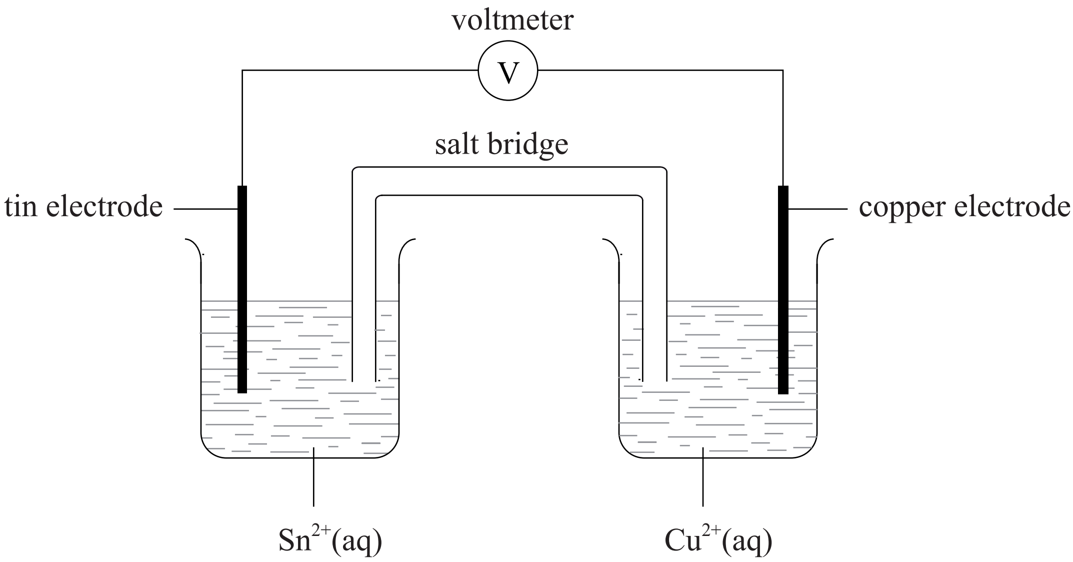
(Question 9 continued)

(b) A voltaic cell is constructed from two half-cells as illustrated below.



(i) Use Table 14 of the Data Booklet to deduce the equation for the spontaneous reaction occurring in this cell. *[1]*

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(ii) Calculate the standard potential for this cell. *[1]*

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(iii) State the conditions necessary for the potential of the cell to equal that calculated in part (b) (ii) using the data from Table 14. *[1]*

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(Question 9 continued)

(c) Using the data below and data from Table 14 of the Data Booklet, predict and explain which metal, cadmium or chromium, may be obtained by electrolysis of separate aqueous solutions of $Cd^{2+}(aq)$ ions and $Cr^{2+}(aq)$ ions. *[2]*

	$E^{\ominus}$ / V
$Cd^{2+}(aq) + 2e^{-} \rightarrow Cd(s)$	-0.40
$Cr^{2+}(aq) + 2e^{-} \rightarrow Cr(s)$	-0.91

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(d) (i) Electrolysis is used in the electroplating of metals. The same amount of current is passed through separate aqueous solutions of $NiSO_4$, $Sn(SO_4)_2$ and $Cr_2(SO_4)_3$ in separate electrolytic cells for the same amount of time. State and explain which cell would deposit the greatest amount (in mol) of metal. Identify the electrode at which the metal is deposited. *[3]*

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(Question 9 continued)

(ii) For the $Sn(SO_4)_2$ cell, suggest **two** factors, other than time and current, that would affect the amount of metal deposited during electroplating. *[2]*

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(e) Nitrogen monoxide may be removed from industrial emissions via a reaction with ammonia as shown by the equation below.

$$4NH_3(g) + 6NO(g) \rightarrow 5N_2(g) + 6H_2O(l)$$

(i) Deduce the oxidation number of the nitrogen in the reactants and product. *[3]*

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(Question 9 continued)

(ii) Deduce the oxidation and reduction half-equations and identify the oxidizing agent for the reaction. *[3]*

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(iii) 30.0 dm^3 of ammonia reacts with 30.0 dm^3 of nitrogen monoxide at 100 °C. Identify which gas is in excess and by how much and calculate the volume of nitrogen produced. *[2]*

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